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AIR FORCE INSTITUTE OF TECHNOLOGY

AIR UNIVERSITY
UNITED STATES AIR FORCE

LEVEL II

SCHOOL OF ENGINEERING

AFIT/GAE/AA/80D-10

VALIDATION OF THE WRIGHT-PATTERSON

VERTICAL WIND TUNNEL.

THESIS

AFIT/GAE/AA/80D-10   James W. Hickman
                       Major   USAF

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VALIDATION OF THE WRIGHT-PATTERSON

VERTICAL WIND TUNNEL

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

by

James W. Hickman, B.S.

Major   USAF

December 1980

Preface

This study represents my attempt to duplicate spin results obtained at the NASA-Langley vertical wind tunnel by using one of their models in the Wright-Patterson vertical wind tunnel. The tests consisted of evaluating the model in the same configurations that were originally accomplished by the NASA. The results were then compared to the original results obtained at the Langley tunnel.

I extend my thanks to my thesis advisor Dr. Robert A. Calico of the Air Force Institute of Technology faculty for his direction in organizing the objectives of this study. Also, I wish to thank Capt. Jim Silverthron and Capt. Roie Black for their support as thesis committee members.

My special thanks also goes to the Air Force Flight Dynamics Lab and to Mr. William Bennett and Mr. Donald Sine at the Wright-Patterson vertical wind tunnel for their untiring help during the test period.

Most of all, I extend a loving thank you to my wife, Patsy, who did more to keep me on the right track during this period than words can express.

James W. Hickman

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List of Symbols

a   speed of sound

Fm   force acting on model

Fp   force acting on prototype

Fr   Froude number

g   acceleration of gravity

l   length

M   Mach number

Re   Reynolds number

V   velocity

α angle of attack

ϕ angle between Y axis of airplane
             and horizontal (roll angle)

ρ density

μ viscosity

Abstract

A spin capability evaluation of the Wright-Patterson vertical wind tunnel was completed using a model of the Bell X-5. The X-5 model was previously spin tested in the NASA vertical wind tunnel at Langley AFB, Va. The study compared results obtained at the NASA-Langley vertical wind tunnel with the test results obtained at the Wright-Patterson vertical wind tunnel. The Langley results were used as the basis for this evaluation. Information was available on spin characteristics of the model with respect to various control surface configurations and recovery attempts using control deflections. The spin tests revealed a stable equilibrium spin and recovery, where applicable, could be established and observed for each corresponding stable equilibrium spin and recovery that was observed at Langley.

VALIDATION OF VERTICAL WIND TUNNEL

FOR SPIN TESTING

I. Introduction

Purpose

The spin maneuver has plagued both military and civil avaiation with numerous loss of aircraft and lives since the birth of powered flight. Spins usually result when the aircraft is flown at a high angle of attack approaching a stalled condition or at a high angle of attack in turning flight. This condition may be inadvertently entered during the various phases of flight from the traffic pattern to the complicated maneuvers encountered during combat by modern jet fighters. The characteristics of a spin are the angle of attack exceeding the stall accompanied by a high yaw rate. Autorotation and sideslip are combined with the downward motion in a spin. If a steady spin is established, the actual path is a vertical spiral. The axis of this spiral is termed the axis of spin. The axis of rotation is fixed to the aircraft and moves about the axis of spin at some fixed distance. (Fig. 1) Since lift is perpendicular to the relative wind it is horizontal and balances the centrifugal force. Drag is vertically upward and opposes the effect of weight. (Ref. 1) Since a spinning motion can cause and often results in the sudden disorientation of the pilot and delays the initiation of recovery procedures, it

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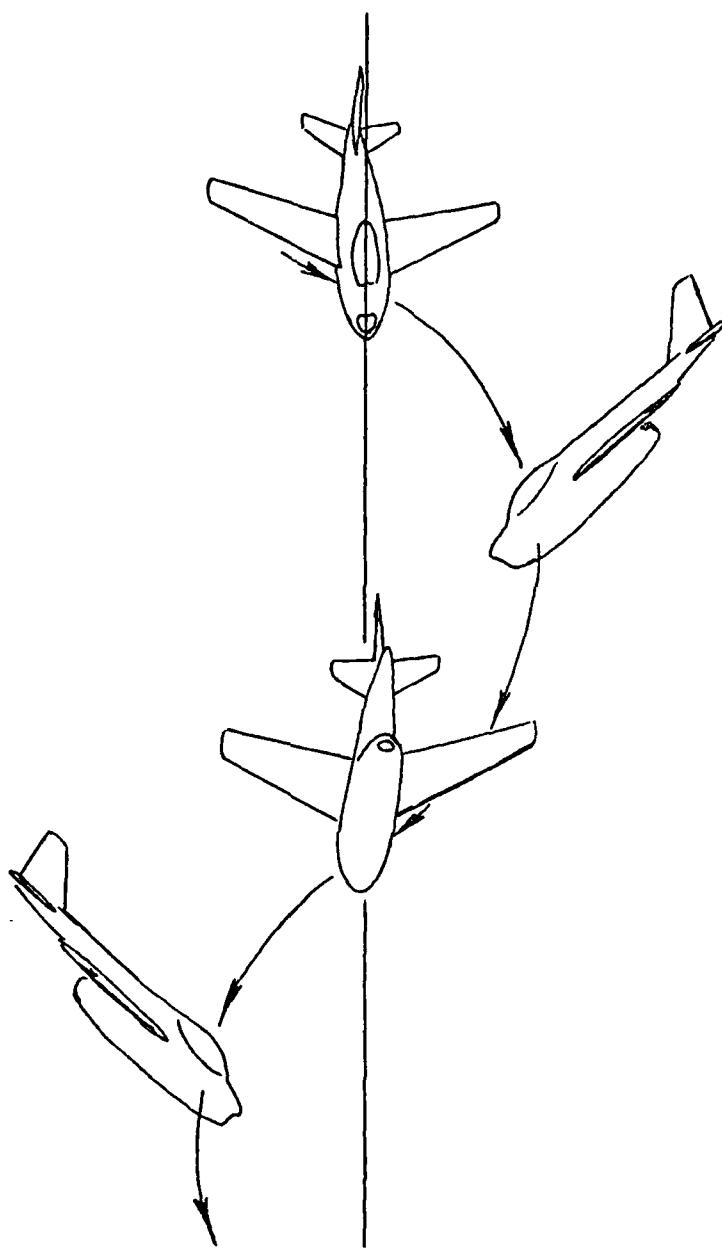
Fig. 1 Spin Profile Representation

becomes more important that we understand and develop methods to return the aircraft to a normal flight condition. This is especially important for the modern jet fighter which inherently has a high rate of descent during a spin. The purpose of this study is not to evaluate the spin characteristics of a particular aircraft but rather to provide a valid tool that is readily available and may be used to evaluate the spin characteristics of state-of-the-art aircraft designs. Therefore, the purpose for the study as to evaluate, validate and operate the Flight Dynamics Lab vertical wind tunnel for spin testing of aircraft.

Test results obtained from a vertical wind tunnel provide valuable information concerning spin susceptibility of aircraft and recovery techniques from the special kind of flight motion known as the spin phenomenon. It is interesting to note, as Melvin N. Gough points out in the AGARD Report 27, February 1956, that the spin tunnel had never missed in predicting the optimum control technique for recovery up to that time. The spin phenomenon occurs where the angle of attack becomes greater than that for maximum lift and flow separation begins. If, at the stalling speed, there is a rolling instability where one wing drops and a form of auto-rotation takes place, the aircraft enters a spin. This spin is in the downward direction and may involve a steep or flat spiral accompanied with violent rotations. The angle of attack ranges between 30 and 40

degrees for a steep spin and in the neighborhood of 60
degrees for a flat spin. The equations used for longitudinal
equilibrium do not reveal a reason for this motion except
when one considers the gyroscopic effect caused by the mo-
ments of inertia of the aircraft about the longitudinal and
normal axis. Therefore, these moments of inertia are quite
important with respect to the spin phenomenon. The fact
that the spin is considered to be significant is primarily
because it is a motion which can be entered inadvertently.
Also, both fighter and trainer aircraft must demonstrate
the ability to satisfactorily terminate a developed spin.
It has been found that in certain cases the control surfaces
may be quite adequate for normal flight conditions, but fall
short of the effectiveness required for recovery from a spin.

Background

Currently, the Wright-Patterson vertical tunnel had
not been used to observe and evaluate the spin characteristics
of aircraft for several years. The primary reason for this
lack of use for spin evaluations has been due to the fact
that the greater amount of spin testing has been concentrated
at Langley. This left the testing at the Wright-Patterson
facility to become less directed at study of the spin phe-
nomenon and more diversified in other areas where a vertical
flow field is required. The tunnel has been well maintained
and improvements incorporated to keep the facility as up to
date as possible.

In recent years there have been many advancements in the design of forward swept wing aircraft. At the present time, the forward swept wing fighter is undergoing study at Wright-Patterson. The availability of the vertical wind tunnel should not be overlooked in the evaluation of this new generation of fighter aircraft since we have very little information available on the spin characteristics of forward swept wing aircraft.

II. Facility

The U.S. Air Force Flight Dynamics Lab 12 Foot Vertical Wind Tunnel is an atmospheric pressure, open jet tunnel without provisions for varying pressure, temperature, density, or viscosity of the air. Construction was begun in 1943 and the tunnel was put into full operation in 1945. It is driven by one 16 foot diameter, 4 bladed, controllable pitch fan with laminated maple blades. The fan is powered by a 1000 horsepower DC motor and has a maximum speed of 875 RPM. The test section shape is a 16 sided polygon which gives a test section dimension of an inscribed circle of 12 feet in diameter. The height of the test section is fifteen feet. Details of the Wright-Patterson vertical wind tunnel are shown in Appendix A.

It is possible to vary the velocity in the test section from approximately 0 fps to 150 fps. Parachute performance tests, model spinning and spin recovery tests, tests of free falling bodies, and rotary wing model tests are some of the tests accomplished in the vertical tunnel. Data is recorded by the use of 16mm motion picture cameras. The tunnel is equipped to give the operator a velocity read-out in feet per second, miles per hour and inches of water. There are two counters shown in (Fig. 2) mounted on the wall of the tunnel, one opposite the operator and one for the recording camera, that gives the run number

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Fig. 2 Run Number Counter

that is being accomplished. A vertical net surrounds
the test section to prevent model damage during test runs.
The net is constructed of nylon and is dyed black to
reduce any glare that would interfere with filming. There
are three "windows", located approximately 120° apart,
that provide access to the test section. At the base
of the net there are 16 hinged boards (flapper boards)
which are used to deflect the flow in the test section and
thereby control the position of the model (Fig. 3 shows
each of these components). The flapper boards are plywood
panels that are mounted on hinges and attached on the peri-
meter of the test section at floor level. The boards are
manually operated and may be used one at a time or in any
combination that is required. Surrounding the entire test
section is safety railing for the protection of observers
that may be near the net during operation. One section
of the railing was removed to provide easy access for the
person making the launch. Normally three people are
required to accomplish a spin test. This includes one
for speed adjustment, one for photography, and one to launch
the model. It is helpful if one or two additional people
are available to assist in operation of the flapper boards.

A Gauss belt, made of 1/2 inch cooper tubing consisting
of 12 turns, surrounds the test section. (Fig. 4 shows a
close-up of Gauss belt). When energized, it sets up a
strong magnetic field inside the test section. The magnetic
field thus created is used to change the control setting of
the model.
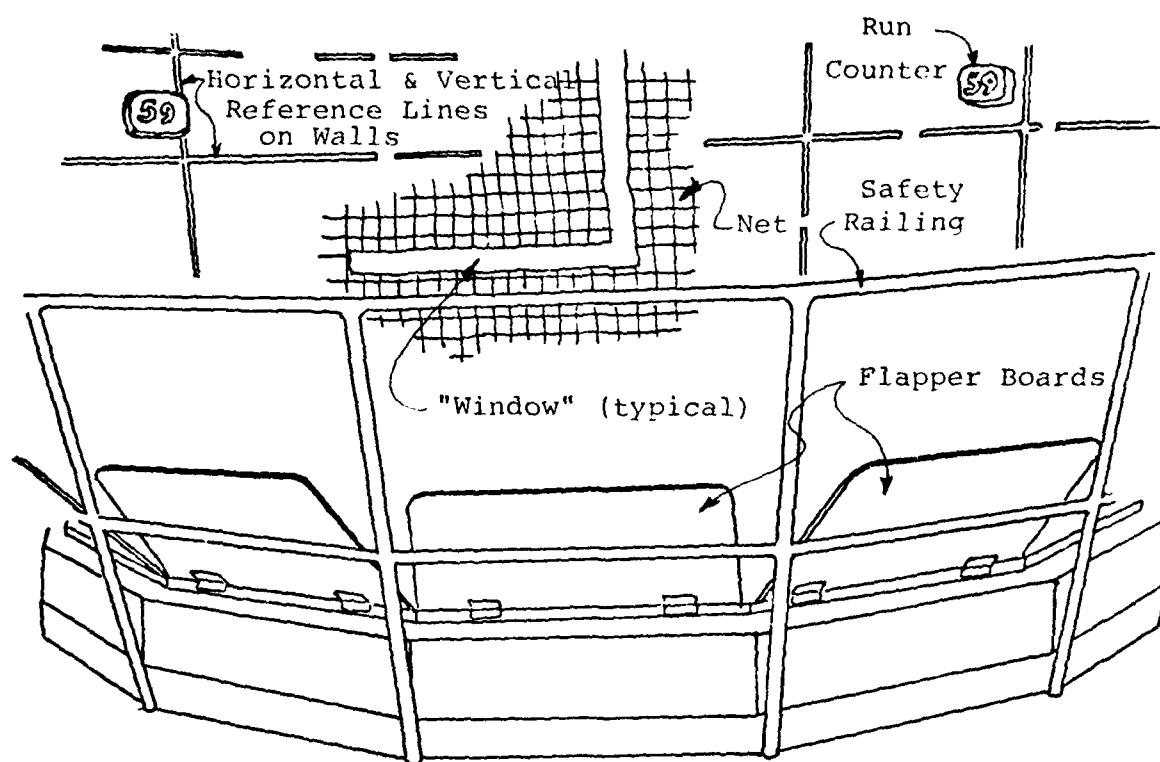
Fig. 3 View of Test Section
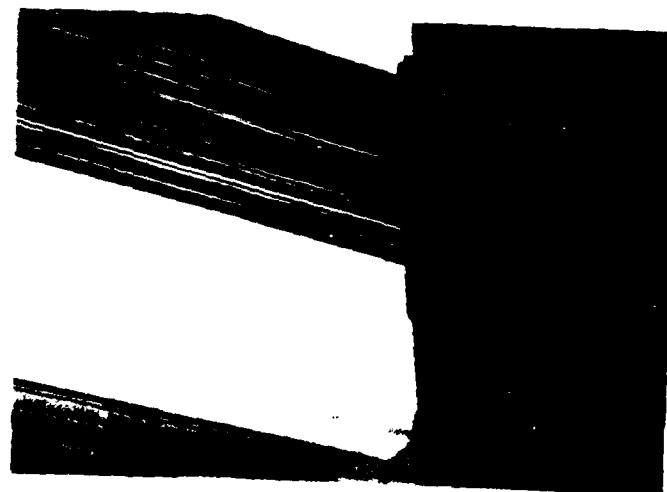
Fig. 4 Close-up View of Gauss Belt

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III. Evaluating the Tunnel

Evaluation of the tunnel began with the examination of the flow in the test section. This was accomplished with a rake consisting of 24 pitot tubes spaced 6 inches apart to cover the overall width of the test section. The rake and probe positions and their coverage are shown in Appendix E. The data was recorded on tape and is on file at the Flight Dynamics Laboratory. A profile of the initial flow is shown in Fig. 5. It was decided alter the flow profile by adding a flow restricting screen on top of the flow straightening section located below the test section. This screen acts to slow down the flow in the center of the test section out to approximately 18 inches from the edge. Fig. 6 shows a typical flow profile after the installation of the screen and the dish that is created to keep the model in the center of the test section. The screen installation is shown in Fig. 7. Spin tunnels have a saucer-shaped velocity gradient in the test section where the centerline velocity is approximately 5 to 10 per cent lower than at the edge which tends to center the spinning model. (Ref. 2) In order to prevent the model from inadvertantly leaving the test section, a net was installed to surround the test section from floor level to the top of the test section. The net also provides protection to observers that may be standing near the test area since the model direction is unpredictable when it is not in a stable spin. The net proved to be a worthy investment
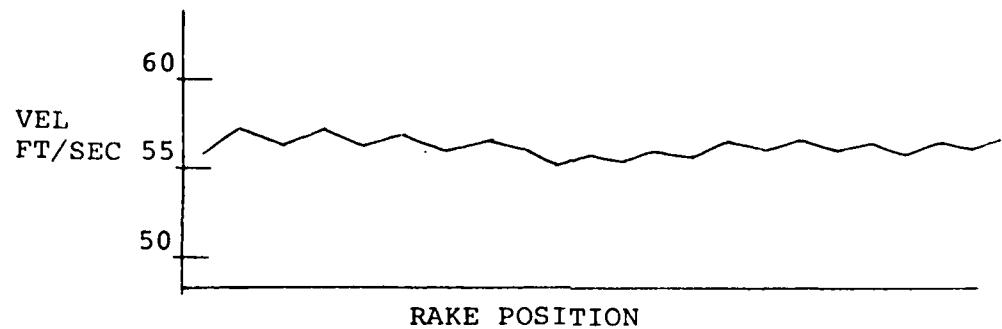
Fig. 5   Profile of Initial Flow (Typical)
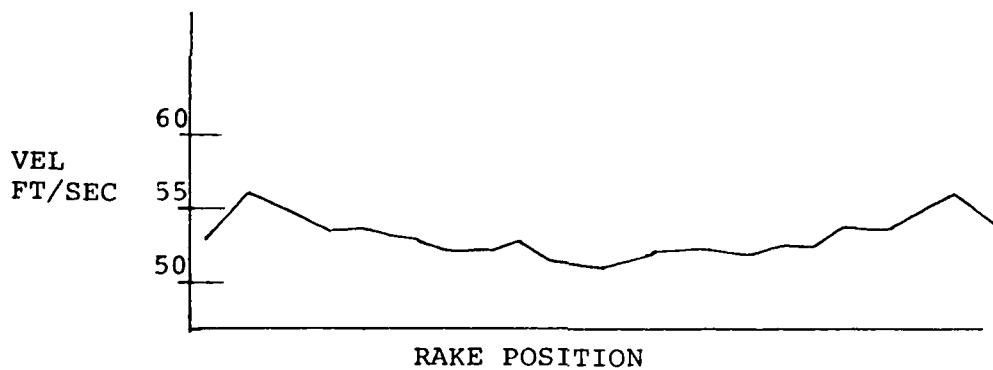
Fig. 6   Flow Profile after Screen Installation
(Typical)

Fig. 7 Screen Installation
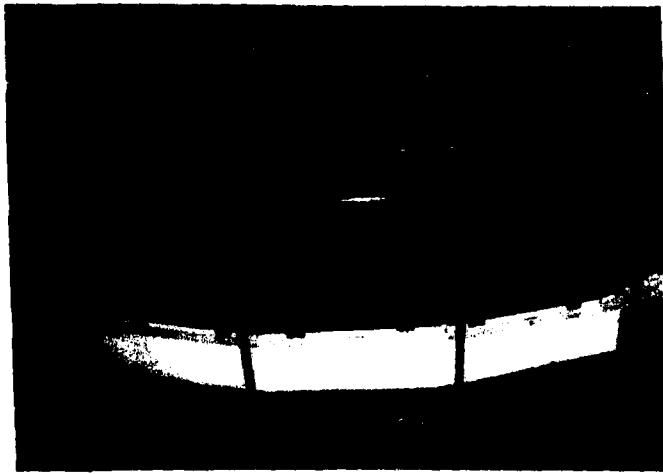
Fig. 8 Net Surrounding Test Section

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during the test runs. Fig. 8 shows the position of the net.

A secondary method to position the model in the flow was the installation of flapper boards around the perimeter of the section at floor level. These boards are normally positioned like the petals of a flower (opened from the center of the test area) and are used to reposition the model while it is in spinning flight. If the model drifts toward the net, a board or combination of boards may be deflected toward thus creating a jet of air that, in effect, pushes the model away from the net and back into the center of the test section. The boards are very effective when the model is at eye level or below. When the model is above eye level, the model becomes very sensitive to the deflection of the boards and their movement must be gentle. If the movement of the boards is too rapid when the model is above eye level, the induced turbulence will tend to "dump" the model from the spinning condition and it must be relaunched.

IV. Modeling Laws

In order to establish dynamic similarity of a model
and its full scale counterpart, the dimensionless quantities
Reynolds number, $\rho \frac{Vl}{\mu}$, Froude number, $\frac{V}{\sqrt{gl}}$, and Mach
number, $\frac{V}{a}$, must be the same in the model test and full
scale flight. If a model test is to be performed using
the same fluid at the same conditions (temperature, density,
viscosity) as full scale, it is only possible to make one
of the three numbers equal to the full scale value for the
model test. It sometimes is in the model than is the
prototype. If more than two importance parameters (Re,M,
Fr) are involved, the construction of a proper model is
not usually feasible. (Ref. 3)

For an aircraft that is in a spin condition, the pre-
dominant forces that it experiences are the inertia and
gravity forces. Since the basic requirement for dynamic
similarity is that the force which act on corresponding
masses in the model and prototype be in the same ratio
($\frac{Fm}{Fp}$ = constant) throughout the entire flow field. The
forces acting on the fluid elements will thus control the
motion of these elements, and it follows that *dynamic simi-
larity will yield similarity of flow patterns*. Consequently,
the flow patterns will be the same in the model as in the
prototype if geometric similarity is satisfied and if the
relative forces acting on the fluid are the same in the
model as in the prototype. Thus, the Froude number in the

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model must be equal to the Froude number in the proto-
type. (Ref. 4) Since the wing is in a stalled condition
during spinning flight, the Reynolds number becomes rela-
tively unimportant. Also, we should note that since the
velocities involved are small, the Mach number becomes
insignificant and can be neglected. By making the test
Froude number equal to the full scale flight Froude number,
the ratio of the inertia forces to gravity forces for
the model test and full scale flight will be equal. The
models needed for spin testing must be similar to the
full scale aircraft both dynamically as well as geometri-
cally. Therefore the dimensions, mass and moments of
inertia must be correctly reproduced. (Ref. 5)

V. Evaluation of Model

Description

The model made available for the tunnel evaluation
was the Bell X-5. Although the X-5 was a variable sweep
aircraft, the model used had the wings fixed at a sweep
angle of 45° (This was one of the many X-5 models used
during the original spin tunnel testing of the X-5).
The model has a wing span of 15 inches and a length of
19 3/4 inches. This is a suggested size for future models
to be used for spin evaluation in the Wright-Patterson
vertical tunnel. The spin model span should be less than
one-fifth that of the test section. (Ref. 2) Therefore,
the tunnel should support a model with a wing span of up
to 2.4 feet. If the spin model size is 1/n full scale,
the other scaling should be as follows for the condition
of equal Froude number. (Ref. 2)

Parameter	Dimension	Model/Full Scale
Length	L	$1/n$
Mass	M	$1/n^3$
Time	T	$1/\sqrt{n}$
Linear velocity	L/T	$1/\sqrt{n}$
Angular velocity	1/T	$\sqrt{n}$
Moment of Inertia	L^2	$1/n^5$

A sample computation for the F-4 would be the following:

Given: Ix_m = 25001 slug-ft^2

Iy = 122186 slug-ft^2 Full Scale

Iz = 139759 slug-ft^2

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If the model scale is 1/29, then $1/n^5 = 1/20511149$.

Use this to multiply each of the moments of inertia

which gives the following for the model:

$$Ix_m = 4.29528 \times 10^{-4} \text{ slug ft}^2 = .061852 \text{ slug-in}^2$$

$$Iy_m = 2.0992 \times 10^{-3} \text{ slug ft}^2 = .3022848 \text{ slug-in}^2$$

$$Iz_m = 2.40112 \times 10^{-3} \text{ slug ft}^2 = .3457612 \text{ slug-in}^2$$

Construction of the X-5 model consisted of balsa-filled

fiberglass wings and tail surfaces with a fiberglass shell

for the fuselage. A fine cut was made around the canopy,

including a small area of the fuselage, to provide access

to the actuator that deflects the control surfaces. Each

control surface is held in place by a single piece of cord

that is attached to the actuator. When the actuator is

released small rubber bands, attached to each control surface,

deflect the surface to the opposite setting. When the

control surface is released by the actuator, a small flag

on a short (4 to 6 inches) piece of string is released

into the slipstream. This provides the means by which

timing for the spin recovery attempt is recorded on film or

video tape. (The canopy is simply held in place by the use

of celephane tape on either side. The tape provides easy

access to the actuator in order that it may be reset for

subsequent runs.) The actuator consists of a permament bar

magnet that trips a hair spring when exposed to the strong

magnetic field of the Gauss belt. The magnet was pivoted

in the center and when the external field was energized

it (the magnet) would become aligned with the field and

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and trip the spring.

Launch Technique

Launching of the model is a coordinated effort on the
part of the tunnel operator and the person making the
launch. The tunnel operator sets an approximate speed
that will support the spinning model and signals the
launcher that he is clear to attempt a launch. The launcher
may indicate to the operator that the speed is too high
or low as the case may be. It was found that the easiest
launch method was to hold the model by the underside of
the fuselage and induce the spin motion by a slight turn
of the wrist as shown in Fig. 9. In order to enter the
model into a left spin it was easier to make the launch
with the left hand. This technique differs from that used
by NASA at the Langley tunnel. Their method is to hold the
model by the nose and toss it into the airstream. This
method would not work during the test and was probably
because of the difference in the sizes of the test section.
(The Langley tunnel is approximately eight feet larger
in diameter).

Model Recovery

Once the equilibrium spin has been established and the
data recorded, the model may be recovered by reducing the
velocity of the airstream and allowing it to settle into
the net below the test chamber. It may then be picked up

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Fig. 9   Launch Technique

by using a pole that has a hook on one end. The hook
should be designed to fit around a certain part of the
model. There is no requirement for special equipment
to catch or pick up the model.

Data Recording

Data from the spin test may be recorded by the use
of high speed movie cameras or on video tape. The use
of the video tape system gives an immediate look at a test
and rough measurements may be obtained without waiting for
processing. High speed movie film provides a very clear
picture of the spin configuration and can be used to accurately
measure angle of attack, roll angle, and rate of spin. The
angle of attack and roll angle are obtained by projecting
the movie on a screen that is marked off in degrees and
stopping the film on specific frames to measure the desired
angles. The camera can be equipped with a data door that
prints elapsed time on the side of the film. With a slight
modification it will also be possible to record the airspeed
and/or other data on the film in addition to time. The
filming is easily coordinated between the operator and
the photographer.

VI. Results

Spin Evaluation

The study was completed to determine if it was possible to match spin results obtained at the Wright-Patterson vertical wind tunnel with corresponding spin results previously obtained at the Langley vertical facility. Table I lists an average angle of attack (α) and an average roll angle (ϕ) for each of the configurations examined. Each numerical average is derived from a minimum of 10 measurements taken from the movie film of each recorded test. Each equilibrium spin was allowed to become well established before the film data was recorded. This permitted any oscillations induced during the launch to become minimized. The observations made during the test runs for each configuration closely resembled the data available in the Langley report. The data furnished by Langley did not indicate the existance of multiple equilibrium spins for any individual control setting. Therefore no attempt was made to determine if other equilibrium spins existed for a given configuration.

Comparison of the velocities for each case revealed a maximum difference of $\pm$ 2 feet per second. This was consistant throughout the evaluation.

Spin Recovery

The steady spins were reproduced in every case that

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had been observed at Langley. These were for all cases
where the ailerons were in a neutral position or where the
ailerons were held against the spin. In the case where
the ailerons were held with the spin, an equilibrium spin
could not be established and the model would dive for
recovery following the launch. This effect of the ailerons
is reflected in Table I. In each case where a recovery
was predicted by use of ailerons, in the Langley results,
a very satisfactory recovery was obtained. For this par-
ticular model the expected recovery results were immediately
evident.

TABLE 1

Wright-Patterson Test Configuration and Results

Spin Direction	Spin Configuration				α (deg)	φ (deg)	Ω (rpm)	Recovery Method (Remarks)
	#	Elevator (deg)	Aileron (deg)	Rudder (deg)				
Left	1	0	0	35 L	43.5	4.6	102	rudder reversal only, 1 thru 18 (steady spin)
	2	25 U	0		43.7	4.6	98	
	3	25 U	15 A		58.6	4.6	105	
	4	0	15 A		60.1	3.5	106	
	5	20 D	15 A		60.3	3.1	106	
	6	20 D	0		58.6	2.6	103	
	7	20 D	15 W					(no steady spin)
	8	0	15 W					
	9	25 U	15 W					
Right	10	25 U	15 A	35 R	59.2	-3.5	102	(steady spin)
	11	0	15 A		60.2	-2.4	105	
	12	20 D	15 A		61.4	-2.3	104	
	13	20 D	0		41.0	-3.3	105	
	14	0	0		44.0	-2.4	103	
	15	25 U	0		41.1	-3.6	99	
	16	25 U	15 W					(no steady spin)
	17	0	15 W					
	18	20 D	15 W					
Left	19	20 D	15 A	35 L	62.0	3.5	109	rudder and aileron reversal, 19 thru 24 (steady spin until control reversal, then model dives out of spin)
	20	0	15 A		60.9	3.1	110	
	21	25 U	15 A		59.8	3.8	105	
Right	22	25 U	15 A	35 R	61.8	-2.9	104	
	23	0	15 A		62.0	-2.4	111	(#21 also exhibited an equilibrium spin at α=47.2 and φ=7.3)
	24	20 D	15 A		63.6	-1.8	110	

U = up, D = down, A = against spin, W = with spin, L = Left, R = Right

VII. Discussion

Baseline Evaluation

The characteristics of the spin information provided
by the NASA at Langley are shown in Table II. Table I shows
the characteristics obtained in the Wright-Patterson facil-
ity for each of the configurations and includes remarks
on the recovery techniques used for each control setting.
In the first set of spins, (i.e. left spin, rudder with
spin) configurations 1 and 2 reflect a notable difference
in the angles of attack when compared to the corresponding
angles of attack contained in the Langley data. Angles
of attack in configurations 3 thru 9 matched the Langley
data very well. The values obtained for ϕ were very close
to the values obtained at Langley.

In the second set (right spin, rudder with spin) the
values obtained also compared very favorably with what was
furnished by Langley except for the angle of attack results
for configuration number 12.

At this point it is important to note the similarity
of the runs made in the left spin direction and those made
in the right spin direction. For each spin in the left
direction, there is a mirror image spin in the right
direction. The mirror image spins are listed in Table III.
This brings up the question of the possibility of multiple
equilibrium spin modes for any given configuration. A
comparison of each left spin with the mirror image right

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TABLE II

Langley Test Configurations and Results

Spin Direction	#	Spin Configuration			α (deg)	φ (deg)	Ω (rpm)	Recovery Method
		Elevator (deg)	Aileron (deg)	Rudder (deg)				
Left →	158	0	0	35 L ——————→	56.7	4.5	109	(rudder reversal)
	155	25 U	0		55.7	4.8	102	
	154	25 U	15 A		61.0	4.6	107	
	159	0	15 A		59.0	3.9	112	
	160	20 D	15 A		58.1	3.5	113	
	161	20 D	0		56.8	5.0	110	
	162	20 D	15 W					
	157	0	15 W					
	156	25 U	15 W					
Right →	142	25 U	15 A	35 R ——————→	58.4	-2.0	102	
	147	0	15 A		57.0	-4.3	111	
	148	20 D	15 A		56.4	-2.0	112	
	149	20 D	0		43.6	-4.2	109	
	146	0	0		48.3	-3.0	104	
	143	25 U	0		43.1	-5.0	96	
	144	25 U	15 W					
	145	0	15 W					
	150	20 D	15 W					
Left →	251	20 D	15 A	35 L →	58.3	5.5	111	(rudder and aileron reversal)
	250	0	15 A	→	58.3	5.2	111	
	249	25 U	15 A	→	57.4	6.1	106	
Right →	259	25 U	15 A	→	58.6	-3.7	105	
	257	0	15 A	→	58.0	-3.9	112	
	258	20 D	15 A	→	59.7	-2.1	112	

U = up, D = down, A = against spin, W = with spin, L = Left, R = Right

spin for each control setting yields some significant
information.   There is very good comparison of the data
with the exception of control configurations 6 and 13.
This exception reflects a difference that is very close
to the difference found between the Langley and Wright-
Patterson results for configurations 1 and 2 as shown
before.   No information was received from Langley that
indicated that more than one spin mode could be obtained.
It was during the examination of the film of configuration
21 that two different angles of attack had been recorded for
identical control settings.   One spin exhibited an α of
59.8 degrees and the second an α of 47.2 degrees.   The dif-
ference being 12.6 degrees which compares to the difference
between the Wright-Patterson results and the Langley infor-
mation for configurations 1 and 2 (13.2 and 12.0 degrees
respectively).   Reexamination of the Langley data shows
that mirror image configuration numbers 161 and 149 (see
Tables II and III) reflect an angle of attack difference
of 13.2 degrees.

Validity of Results

From the documented testing that had been done in the
Langley facility, it can be concluded that two (at least)
equilibrium spins exist for each given control configuration
of the X-5 model.   The difference in angle of attack that at
first appears to be in error is not easily understood until
each spin result is compared with the mirror image spin.

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TABLE III

Mirror Image Spins

Left Spin	Right Spin
1 (158)	14 (146)
2 (155)	15 (143)
3 (154)	10 (142)
4 (159)	11 (147)
5 (160)	12 (148)
6 (161)	13 (149)
7 (162)	18 (150)
8 (157)	17 (145)
9 (156)	16 (144)
21 (249)	22 (259)
20 (250)	23 (257)
19 (251)	24 (258)

Example: Run #3 has a mirror image in run #10, etc.

Note: the Langley run numbers are shown in paraenthesis

The Langley information confirms the existance of the
multiple spin modes in configurations 158/146, 155/143,
and 161/149.

VIII. Conclusions and Recommendations

Conclusions

Comparison of the results obtained at the Wright-
Patterson vertical wind tunnel with the information received
from Langley led to the conclusion that the Wright-Patterson
facility does provide accurate spin date. This conclusion
is based on having been able to duplicate the results ob-
tained by Langley. Also significant, was the discovery
of two equilibrium spin modes which differed by approxi-
mately 8 to 14 degrees depending on the control surface
settings. The possibility of the existence of two equili-
brium spins was not a factor that was being considered nor
had any information directly indicating this been received
from Langley. The discovery came from careful examination
of the spin test films made at Wright-Patterson followed
by reexamination of the Langley results.

Models are normally launched by hand into the test
section with an initial rotation. Thus, several more spins
are repeated in the tunnel then in actual flight. Therefore,
it is possible to produce a spin that could not be easily
gotten into with the full scale aircraft. It is important
to note that given enough time, some pilot will manage to
experience such a spin. It is when a pilot gets into a spin
that the information obtained in the spin tunnel becomes of
value. For instance, it is not immediately evident to some
pilots that the ailerons should be positioned with the

direction of the spin. This is the type of information
that spin testing is ultimately aimed at and possibly the
best argument for making use of the Wright-Patterson ver-
tical wind tunnel.

Recommendations

The vertical wind tunnel is a facility which is inexpen-
sive to operate and capable of yielding important information
in the area of spin susceptibility and recovery techniques
of modern aircraft. The tunnel is in excellent operating
condition and should be used to the fullest to make spin
evaluations of aircraft being studied at Wright-Patterson.

The Gauss belt was used to reverse the control surfaces
during this test. This method is not only time consuming
but has been outdated by the availability of modern radio
control devices. By using radio controls to actuate the
control surfaces, the effectiveness of the tunnel can be-
greatly enhanced. This can be illustrated by considering
the number of times the control surfaces could be changed
during a single run. With the Gauss belt the number would
be limited to one, whereas radio control permits any number
of control surface deflections in addition to being able to
examine intermediate positions. Radio controls are readily
available and are relatively inexpensive. Radio controlled
models are currently being used at the Langley tunnel.

Instrumentation for determining the moments of inertia
of any models tested in the tunnel will be a necessity for

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spin evaluation. At the present time this is the only component that is not readily available in order to accomplish a spin test. Selection of the instrument could be made with advisement from the NASA at Langley.

Although design studies and spin tunnel tests play an important roll in design corrections, considerable judgement backed by experience must also be employed in making the determination as to whether or not the proposed design will or will not have adequate control. That desired experience and judgement can only be gained through continued use of the vertical wind tunnel as a tool for the spin analysis of aircraft.

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Appendix A

Type	Closed Annular Return
Overall Size	86' high, 56' 8" diameter
Centerline Circuit	
Test Section Type	Open Throat
Test Section Shape	16 Side Polygon
Test Section Dimension	12' Across Inscribed Circle
Test Section Length	15' High
Contraction Ratio	9.9 to 1
Maximum Velocity	102 mph
Maximum Mach Number	0.14 mph
Maximum Dynamic Pressure	25 psf
Power	1000hp DC Motor, Ward Leonard Speed Control System
Energy Ratio	0.65
Temperature Control	None
Stagnation Temp. Range	Approx. Atmospheric
Operating Pressure Range at Fan Section	Approx. Atmospheric
Air Drive	One 16' Dia. 4-Bladed, Controllable Pitch Fan With Laminated Maple Blades
Drive Shaft	10' Long, 6" Dia., Solid Steel Shafts
Maximum Fan RPM	875
Model Support System	Horizontal Parachute Test Strut
Auxiliary Equipment	Position-airspeed-time, data recording 16 mm motion picture cameras
	Electronic data recording equipment available on limited basis
Type of Tests	Parachute Performance Tests Model Spinning and Spin Recovery Tests Tests of Free Falling Bodies Rotary Wing Model Tests
Estimated Cost	$750,000
Construction Begun	March 1943
Tunnel Put in Operation	May 1944 (Limited) August 1945 (Full)
Reimbursable Rates (DoD User)	$400 per day (Civilian Labor) Plus Photographic Materials and Processing for Specific Test Requirements

VERTICAL WIND TUNNEL
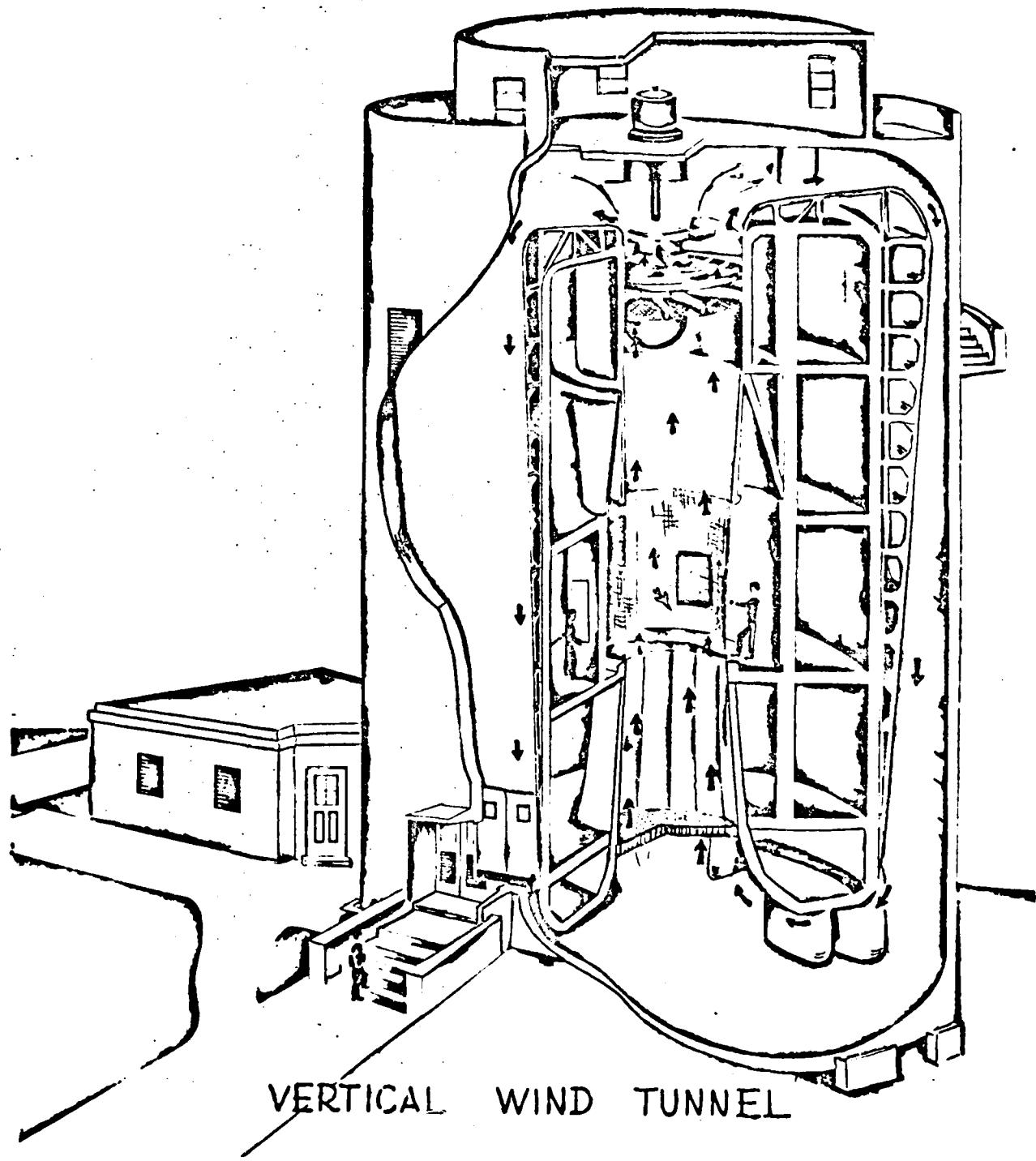
Appendix C

Bell X-5 Model Description

Dimensions

Wing Span	15 inches
Length	19 3/4 inches
Horizontal Stabilizer (span)	5 3/4 inches
Vertical Stabilizer (height)	4 inches

Control Surface Settings

rudder	$\pm 35^{O}$
elevator	$+20^{O}$ to -25°
aileron	$\pm 15^{O}$

APPENDIX D

AFDAL VERTICAL WIND TUNNEL

OPERATIONS CHECK LIST

WIND TUNNEL START-UP

	FUNCTION	ACTION	REACTION	REMARKS
1.	Request Electrical Power for 1000 H.P. Vertical Wind Tunnel Motor	Telephone Central Ext. 56902	Electrical Power Available at Power Panel in M.G. (Motor Generator) Room	Note: If entrance to fan section should be required – shut off fan and shut off M.G. set. Obtain keys to lock for fan section access door from tunnel operator. Tunnel Operator can not start M.G. set until keys have been returned to the operator and inserted in interlock system.
2.	IN M.G. ROOM: Connect A.C. Power to Control Circuits	Switch Circuit Breaker No. 6 (On Power Panel to ON Position)	A.C. Power connected Thyristor Power Supply Transformer, basic regulator, and 110V A.C. Control Circuits	
3.	IN M.G. ROOM: Connect Generator Field to Power Supply	Switch Circuit Breaker No. 5 (on Power Panel) to ON Position	Connects Generator Field to Thyristor Power Supply. Reset Circuit is closed	
4.	IN M.G. ROOM: Energize RESET Circuitry	Push RESET Button (located on upper control cabinet panel, bottom left corner)	RESET Relay energized OVERLOAD Relay is reset. GREEN Light (adjacent to RESET Button) lights up, indicating Ready Condition	
4a.	Lock outside test facility door			
4b.	Turn on intercom			

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	FUNCTION	ACTION	REACTION	REMARKS
5.	Get ready for M.G. Start and Tunnel Blower Run-up	Move to First Floor Test Station OUTSIDE CONTROL CONSOLE: Console should be GREEN (Disregard Gauss Ring Lamps)		
6.	AT TEST STATION: Energize Cooling Blower	OUTSIDE CONTROL CONSOLE: Move CBF Handle to CLOSE position	Cooling Blower Fan running indicator Light (CBF)	
7.	AT TEST STATION:	OUTSIDE CONTROL CONSOLE: Move OCB Handle to CLOSE position	M.G. Set starting. Indicator light YELLOW; after 1-2 Sec. RED M.G. Set operating	If M.G. Set Fails to start, contact FDMT, Bldg 25C (Mr. Leo Conner, Ext 52137) ascertaining that Power Circuit Breaker for VWT is closed.
8.	AT TEST STATION: Check SPEED CONTROL Rheostat	Turn SPEED CONTROL Rheostat to indicate 000 on both the INSIDE and OUTSIDE control panels		
9.	AT TEST STATION: Select Control Station from which Speed Control is to be exercised	Move INSIDE/OUTSIDE Selector Switch on INSIDE Control Panel to desired position	Switches Speed Control to desired Control Station	Secure Test Area. Close Doors to Test Section. Check and Calibrate Test Instrumentation, if required

WIND TUNNEL BLOWER IS NOW READY FOR RUN-UP

NOTE - Five (5) to Ten (10) Minutes should be allowed between Function 2 and Function 10 to insure sufficient stabilization of Control Modules

| FUNCTION	ACTION	REACTION	REMARKS
10. AT TEST STATION Turn Interlock key ON	OUTSIDE CONTROL PANEL Remove Interlock key from hook and insert in Interlock	Power becomes available for Wind Tunnel Blower	
11. AT TEST STATION: Energize Wind Tunnel Blower Motor	AT SELECTED CONTROL PANEL: Push START button	Indicator lights located on OUTSIDE Control Panel (below PHOTO LIGHTS Switch Handle) switch from GREEN to RED. Tunnel Fan Blades are idling.	INSIDE/OUTSIDE Switch Setting (transfer of control) may still be made at this function.
12. AT TEST STATION: Adjust Airflow Speed in Test Section	AT SELECTED CONTROL PANEL: Turn SPEED CONTROL Rheostat to desired Setting	Velocity of the Airflow increases or decreases to desired values	If INSIDE/OUTSIDE Switch Setting is changed, W.T. Blower will decelerate rapidly and go to idling. To restart return to Function 8.

PROCEDURE FOR EMERGENCY SHUT-DOWN OF WIND TUNNEL BLOWER

| FUNCTION	ACTION	REACTION	REMARKS
CONTROL EXPERIMENTAL TESTING			
AT TEST STATION: Emergency Stop of W.T. Blower	Push STOP Button on either INSIDE or OUTSIDE Control Panel	Regenerative (Very Rapid) Braking of W.T. Blower Motor idle. Indicator lights located on OUTSIDE Control Panel (below PHOTO LIGHTS Switch Handle) switch from RED to GREEN (at idling)	To start W.T. Blower again, return to Function 8.

WIND TUNNEL SHUT-DOWN

	FUNCTION	ACTION	REACTION	REMARKS
1.	AT TEST STATION: Return Airflow Speed in Test Section to Zero	AT SELECTED CONTROL PANEL: Turn SPEED CONTROL Rheostat to indicate 000	W.T. Blower decreases Idle Speed	
2.	AT TEST STATION: De-energize Wind Tunnel Blower Motor	Push STEP Button on either INSIDE or OUTSIDE Control Panel	W.T. Blower Motor Stops Indicator Lights on OUTSIDE Control Panel (below PHOTO LIGHTS Switch Handle) switch from RED to GREEN	
3.	AT TEST STATION: Turn Interlock Key OFF	OUTSIDE CONTROL PANEL: Remove key from Inter-lock and replace on hook	Power no longer available for wind tunnel blower	
4.	AT TEST STATION: De-energize Cooling Blower	OUTSIDE CONTROL CONSOLE: Move CBF Handle to OFF Position	Cooling Fan Motor Stops. Indicator Lights (CBF) switch from RED to GRREN	
5.	AT TEST STATION: De-energize M.G. Set	OUTSIDE CONTROL CONSOLE: Move OCB Handle to OFF Position	M.G. Set Stops. Indicator Lights switch from RED to GREEN	
6.	AT TEST STATION: Inform Central Dispatch of Tunnel Shut-Down	Telephone Central Dis-patch Ext. 52257		
7.	IN M.G. ROOM: Remove Generator Field from Power Supply	Switch Circuit Breaker No. 5 (on Power Panel) to OFF Position	Power removed from Generator Field. RESET Relay de-energized. GREEN Light (adjacent to RESET Button) extinguished	

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| FUNCTION	ACTION	REACTION	REMARKS
8. IN M.G. ROOM: Remove A.C. Power from Control Circuits	Switch Circuit Breaker No. 6 (on Power Panel) to OFF Position	A.C. Power removed from Thyristor Power Supply Transformer, basic Regulator, and 110V A.C. Control Circuits	

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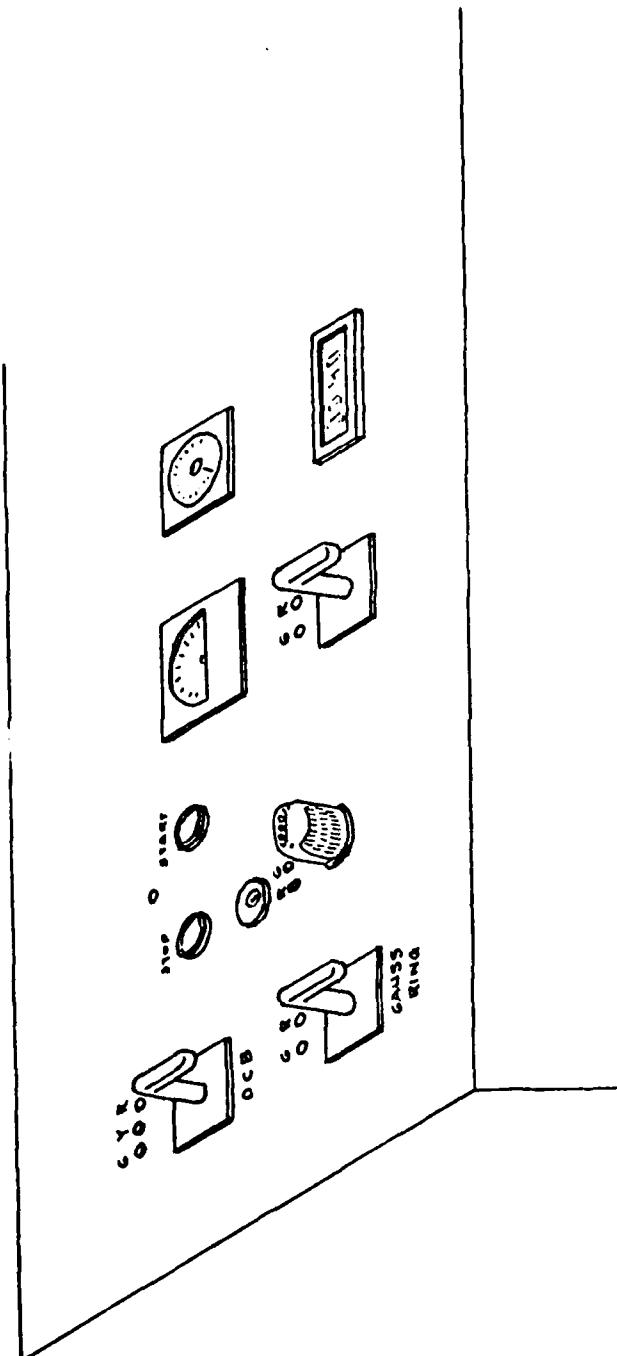
OPERATOR CONTROL PANEL

APPENDIX E

VERTICAL WIND TUNNEL
FLOW FIELD SURVEY
RAKE AND PROBE POSITIONS

RAKE POSITIONS

PROBE POSITION

$17\frac{1}{2}$ PROBE LENGTH

$1\frac{1}{2}$ STATIC PORT LOCATION

12' FACILITY THROAT

LEVEL 4   93"
LEVEL 3   69"
LEVEL 2   45"
LEVEL 1   21"

VERTICAL WIND TUNNEL
FLOW FIELD SURVEY
RAKE AND PROBE POSITIONS
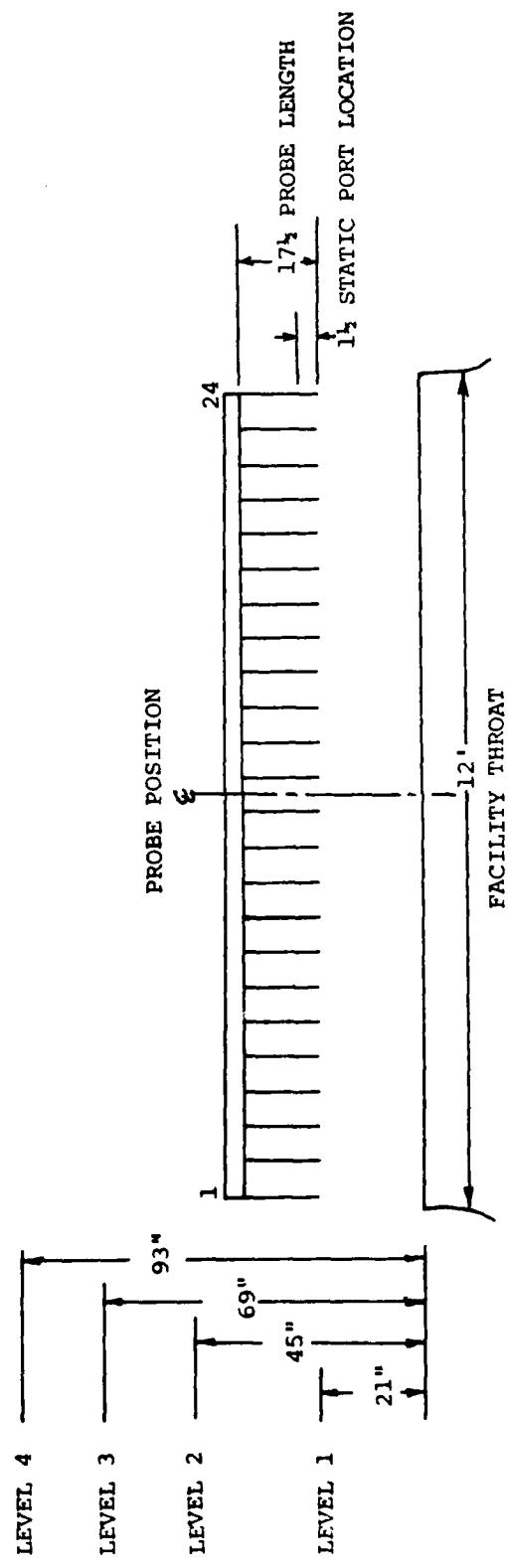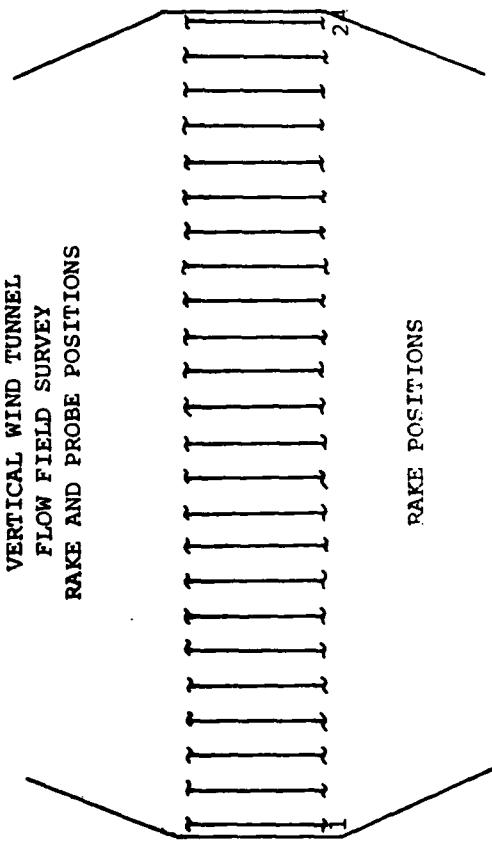
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24 ← PROBE POSITIONS → 1
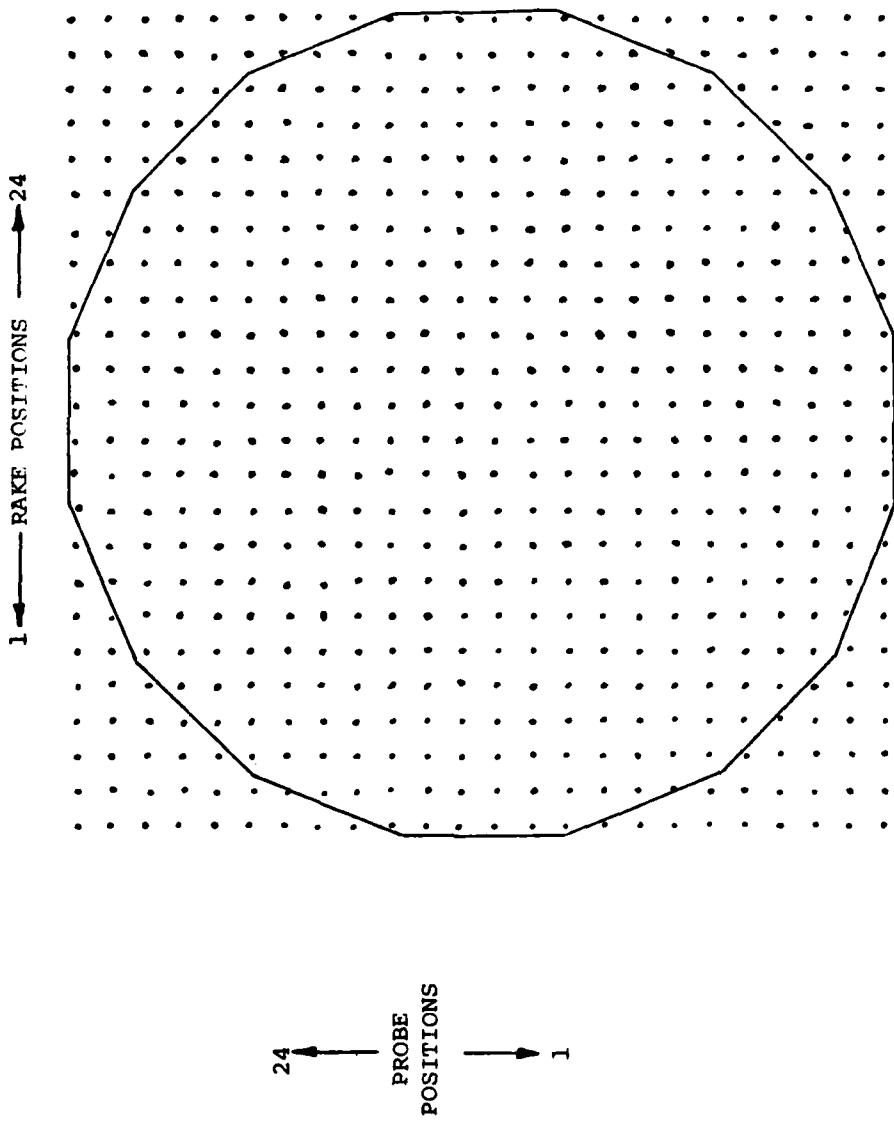
OPERATOR'S CONSOLE

Vita

James W. Hickman was born 9 November 1940 in Fairmont,
West Virginia. He graduated from Farmington High School,
Farmington, West Virginia in 1958 and attended Fairmont
State Teachers College until entering the Air Force through
the Aviation Cadet Navigator/commissioning program in November
1961. He was graduated and received his commission in October
1962 after which he was assigned to Dover AFB, Delaware, as
an instructor navigator in the C-124. His assignment involved
a world-wide flying mission and it was in this capacity that
he functioned until he left active duty in January 1967. In
June 1967, he returned to school at Wichita State University,
Wichita, Kansas and received the degree of Bachelor of Science
in Aeronautical Engineering in June 1969. Upon graduation,
he was employed as an engineer with Cessna Aircraft Company,
Wichita, Kansas until he was recalled to active duty in June
1971. On return to active duty, he was assigned as navigator
on KC-135's and was stationed at McConnell AFB, Kansas, and
K.I. Sawyer AFB, Michigan. He served as instructor navigator
and as a Standardization/Evaluation navigator until February
1978 at which time he became Wing Navigator. He functioned
in this position until reporting to the Air Force Institute
of Technology in May 1979 where he was enrolled in Graduate
Aeronautical Engineering.

His permanent address is 830 Toh-N-Hah Trail, Wichita,
Kansas, 67212.

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Spin-aircraft

Vertical Wind Tunnel

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A spin capability evaluation of the Wright-Patterson vertical
wind tunnel was completed using a model of the Bell X-5. The X-5
model was previously spin tested in the NASA vertical wind tunnel
at Langley AFB, Va. The study compared results obtained at the
NASA-Langley vertical wind tunnel with the test results obtained at
the Wright-Patterson vertical wind tunnel. The Langley results
were used as the basis for this evaluation. Information was
available on spin characteristics of the model with respect to

20. various control surface configurations and recovery attempts using control deflections. The spin tests revealed a stable equilibrium spin and recovery, where applicable, could be established and observed for each corresponding stable equilibrium spin and recovery that was observed at Langley.

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